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Visualizing Egocentric Path Descriptions: A Computational Model

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The ability to visualize spatial information from verbal descriptions is an important component of human cognition. A common example is generating a 'mental picture' of driving directions. Such directions can be given either from an external viewpoint, as if viewing a map (exocentric description, e. g. 'Left' is always West), or from the point of view of a traveler moving along the path (egocentric description, e.g. 'take a right, go 1 block, then turn left…').

Directions for driving imply a horizontal-plane, two-dimensional mental image, but one can also describe paths through 3D space. We have studied the capacity of people to visualize complex 2D and 3D paths using the Path Visualization (PV) task, which provides an objective measure of visualization accuracy. We developed an ACT-R model of visualization capacity for exocentrically-described paths (Lyon, Gunzelmann & Gluck, 2008). According to this model, the capacity to visualize an exocentric path description is limited primarily by decay and spatial interference in an exocentric-viewpoint image constructed in visuospatial working memory.

Here we extend this model to account for people's ability to visualize complex *ego*centrically-described paths. We suggest that the primary internal representation used for egocentric-path visualization is the same as in the exocentric case -- an exocentric-viewpoint mental map. This implies that egocentric descriptors would need to be converted to an exocentric reference frame before they could be added to the map. If this conversion process involves additional cognitive operations, and these operations take time, then items in spatial working memory should undergo more time-based activation decay for egocentric descriptors than for exocentric descriptors. Thus we hypothesized that accuracy for egocentrically-described paths would be lower than accuracy for exocentrically-described paths.

Model Predictions

Since our hypothesis was that egocentric-to-exocentric conversion time would be the primary cause of any accuracy difference between exocentric and egocentric conditions, we developed a model of egocentric path visualization by starting with the exocentric-case model and adding an egocentric-to-exocentric conversion process. We then conducted a rather strict test by using all of the same parameter values that were used in the model for exocentric descriptors, and adding only one parameter – the execution time of the egocentric-to-exocentric conversion process – to the model for the egocentric case. As shown below, the additional time required by this process does indeed cause the model to predict that visualizing egocentrically-described paths will be less accurate than the exocentric-description case.

Method

Each of thirteen participants completed ten 30-trial PV sessions, five with exocentric path descriptions, five with egocentric. On each trial, 15 unit-length path segment descriptions (e.g. 'Left 1') were presented for 2 sec. each. In the exocentric condition, directions were relative to a fixed reference frame, so that 'Left' would always refer to the left side of an imaginary 5 x 5 x 5 three-dimensional space within which the paths were generated. In the egocentric condition, directions were relative to the current facing of a hypothetical traveler on the path. In both conditions, the participant read each path segment description, decided whether the endpoint of that segment intersected with any previously presented part of the path, and responded *yes* or *no* with a keypress. Half of the paths could wander randomly through three dimensions; the other half were 2D paths constrained to either a coronal ('picture'), sagittal, or horizontal plane through the center of the space.

Results

As predicted, paths described exocentrically were visualized more accurately than paths described egocentrically ($F(1,12)=18.5$, $p<0.001$). There was no overall effect of path type. Model predictions fell close to human overall accuracy for both exocentric and egocentric conditions (Figure 1). The egocentric model fit was obtained using an egocentric-to-allocentric conversion time of 700 msec.

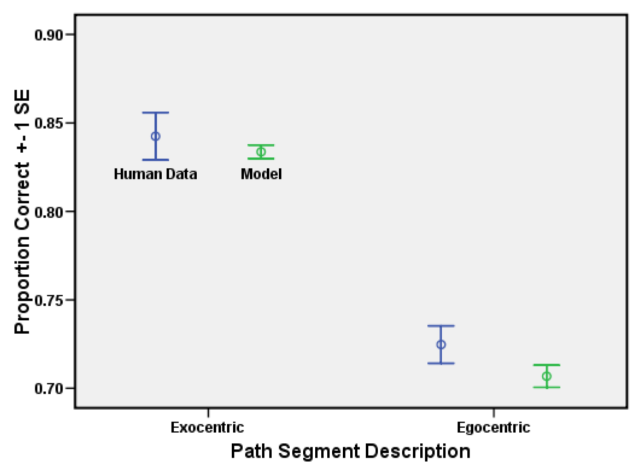

Figure 1. Visualization accuracy for exocentrically- and egocentrically-described 3D and 2D paths.

Although the model accounts well for the overall difference in accuracy between egocentric and exocentric conditions, it does not track human accuracy for different path types within the egocentric condition. In particular, the model predicts better performance for 3D paths than for 2D paths, whereas people certainly do not find 3D paths easier. A possible explanation for this discrepancy is that many paths in the 3D condition require particular kinds of ego-to-allo transformations that people find especially difficult. For example a virtual traveler on the path in the 3D condition would often be head-down, or in some other unusual body orientation, making it difficult for people to translate terms such as ‘up’, or ‘left’ into an absolute reference frame.

We tested the relative difficulty of different kinds of ego-allo transformations in an ancillary study in which movements through the same 5 x 5 x 5 virtual grid were visually depicted (from an egocentric perspective), rather than verbally described. Participants were allowed all the time they needed to accomplish each ego-to-allo translation, visualize the next segment, and produce a response. The data reveal a generally systematic increase in response time as either facing direction or body axis direction deviated from a forward-facing, upright alignment. People took an average of about 250 additional msec. per 90 deg. of facing misalignment. For body axis orientation, the time required for each 90 deg. of misalignment was roughly equal to three 90-deg. ‘steps’ of facing misalignment, or 750 msec.

We therefore modified the model by refining ego-to-allo translation into two components: (1) a perspective-taking process that requires additional time as body axis and facing misalignment from upright-forward increases, and (2) a segment generation process that requires a constant amount of time. The average total time for these processes was constrained by the previous model fitting to be 700 msec. By default, the generation process required one 50-msec. ACT-R cognitive cycle, leaving 650 msec. for the perspective-taking process. Because the average number of perspective misalignment ‘steps’ was 4, each step time was set at 650/4 (approx. 162 msec.). This change required an adjustment in retrieval threshold from -0.9 to -0.7 to maintain overall accuracy comparable to the human data.

The difference between the 250-msec step time obtained in the ancillary study and the 162-msec time used by the model in the main study is probably due to the 2-sec. deadline imposed for responses in the latter. This deadline was necessary to assure that performance was driven by factors (such as decay and interference) that influence spatial visualization itself, and not by non-spatial strategies that could conceivably be used given unlimited time.

This model resulted in a substantially better (but not ideal) fit to the data for different sub-conditions (Figure 2). A better fit might have been obtained by optimizing the division between perspective-taking and segment generation processes, but this would have required another parameter.

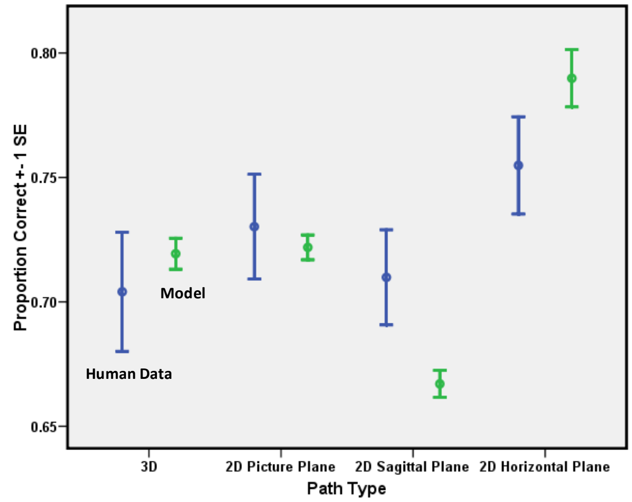

Figure 2. Human data vs. revised model for 3D paths and different kinds of 2D paths.

Conclusions

Human capacity to construct a mental image of new, complex spatial material is sharply limited. In particular, when people try to visualize a verbally described path, capacity limits are well-described by a model in which the activation of each new segment decays with time, and segments that are nearby in imaginary space interfere with each other (Lyon, Gunzelmann & Gluck, 2008).

Here we have shown that path visualization accuracy depends on the nature of the path description. If the path is described in exocentric terms, using fixed reference directions external to the path itself, accuracy is higher than if it is described in egocentric terms, from the point of view of a traveler on the map, in which the absolute direction of ‘left’ and ‘right’, etc. depend on the direction the traveler is imagined to be facing.

The success of the model in the egocentric case suggests that the basic processes that limit visualization accuracy (decay and interference) operate for both kinds of descriptions. The key difference is that egocentric descriptions require a translation process to convert them to fixed, exocentric directions. Under the conditions of this study, ego-allo translation required, on average, about 700 msec., but the time varied considerably depending upon the degree of misalignment of a virtual traveler on the path from an upright, forward-facing orientation.

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Reference

Lyon, D. R., Gunzelmann, G., & Gluck, K. A. (2008). A computational model of spatial visualization capacity. *Cognitive Psychology*, *57*, 122–152.